Brood Stock Acquisition for Atlantic Salmon *(Salmo salar)* Enhancement Activities in Newfoundland: A Review of Related Factors and Suggested Criteria

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May 1987

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1931

Fisheries and Oceans Pêches et Océans

Canada

87-05352/

Canadian Manuscript Report of Fisheries and Aquatic Sciences

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Canadian Manuscript Report of
Fisheries and Aquatic Sciences 1931

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BROOD STOCK ACQUISITION FOR ATLANTIC SALMON (*SALMO SALAR*) ENHANCEMENT ACTIVITIES IN NEWFOUNDLAND: A REVIEW OF RELATED FACTORS AND SUGGESTED CRITERIA

by

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Cat. No. Fs 97-4/1931E ISSN 0706-6473

Correct citation for this publication:

Anderson, T. C. 1987. Brood stock acquisition for Atlantic salmon (Salmo salar) enhancement activities in Newfoundland: a review of related factors and suggested criteria. Can. MS Rep. Fish. Aquat. Sci. 1931: iv + 26 p.

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ABSTRACT

Anderson, T. C. 1987. Brood stock acquisition for Atlantic salmon (Salmo salar) enhancement activities in Newfoundland: a review of related factors and suggested criteria. Can. MS Rep. Fish. Aquat. Sci. 1931: iv + 26 p.

The increasing requirement for brood stock for Atlantic salmon enhancement projects in Newfoundland is explained in terms of the expanding role of the public in developing the salmon resource. Legislation governing live fish collections, transfers and introductions is reviewed. Factors affecting diversity between salmon stocks are examined and various options for brood acquisition are presented. The egg deposition requirement of stream and pond habitat in Newfoundland is discussed in the context of safeguarding donor stream production. Various enhancement techniques are evaluated on the basis of brood stock requirement, cost-effectiveness and results from past initiatives. Suggested criteria aimed at ensuring both suitable brood stock and appropriate enhancement technique selection, while protecting donor stream production, are presented. In addition, the priority of brood stock removal in the overall management of Atlantic salmon is discussed.

RÉSUMÉ

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RÉSUMÉ

Le besoin croissant en stocks d'ensemencement pour la mise en valeur du saumon de l'Atlantique à Terre-Neuve est expliqué au plan du rôle plus important joué par le grand public dans le développement de cette ressource. On examine les lois qui régissent la collecte, le transfert et le déversement de poissons vivants ainsi que les facteurs qui influent sur la diversité des stocks de saumon. On présente divers moyens d'acquérir des stocks d'ensemencement et on examine les besoins pour la ponte dans les cours d'eau et les étangs en regard du maintien de la production dans le cours d'eau donneur. Diverses techniques de mise en valeur sont évaluées en fonction des besoins en stocks d'ensemencement, de l'efficacité par rapport au coût et des résultats de travaux antérieurs. Sont aussi présentés des critères destinés à assurer le choix approprié de stocks d'ensemencement et de techniques de mise en valeur tout en tenant compte du maintien de la production du cours d'eau donneur. De plus, on se penche sur la priorité que pose le prélèvement de stocks d'ensemencement dans la cadre de la gestion globale du saumon de l'Atlantique.

INTRODUCTION

Atlantic salmon (Salmo salar) enhancement activities in Newfoundland underwent a period of expansion in the 1960s and 1970s when several successful projects were implemented. During this period many techniques were piloted and refined by the Department of Fisheries and Oceans (DFO) and strategies were developed to enhance salmon stocks of the rivers of Newfoundland. Interest by the public has also grown, due to both increased recreational and commercial salmon catches in the vicinity of enhancement projects and regional development and employment opportunities resulting from such projects. In addition, publicity generated from salmon enhancement projects, coupled with the on-the-job experience of employees, has raised awareness of the Atlantic salmon resource province-wide.

Since 1980 local public groups (conservation clubs, development associations, community councils, etc.) have become involved in enhancement projects to the point of actually sponsoring such activities. These groups, working under DFO authorization, have successfully acquired funds (mainly from agencies other than DFO) and undertaken enhancement projects which utilize much of the technology developed during earlier DFO enhancement initiatives. DFO has placed emphasis on scientific and technical support, information dissemination and regulatory control in overseeing these activities. In addition, research is continuing into standing water production of salmon and techniques for rearing juvenile salmon in semi-natural conditions. In 1984, a comprehensive plan for an extensive salmon enhancement project in Newfoundland and Labrador was released (Anon. 1984). Of the 21 projects proposed in this document over one-half would utilize public involvement in the planning, feasibility and implementation phases.

A major constraint on publicly-sponsored projects is the lack (perceived or otherwise) of brood or seed stocks required for initial restorative or developmental activities. Brood sources in Newfoundland are limited to wild stocks as the only salmon hatchery is involved solely in development of suitable stocks for aquaculture (pen-rearing) activities. The use of wild stocks places additional costs on most enhancement projects. Such costs, related to trapping, holding, transfer, disease surveys, etc. of brood stock, must be balanced against the benefits derived from an enhancement undertaking. Such benefits include not only additional salmon produced and harvested but also employment, regional development and environmental preservation that can be attributed to salmon enhancement. Throughout the following text, emphasis is placed on a cost-effective approach to brood stock acquisition; a review of benefit-cost analysis in Newfoundland Atlantic salmon enhancement activities is presented in Anon. (1984).

The purpose of this publication is to develop and present criteria for wild brood stock acquisition that conform to existing legislation and are both scientifically sound and cost effective. In addition, the overall priority of brood stock acquisition in terms of the salmon resource is discussed. The body of the report is divided into the following four sections:

(i) a review of the legislation concerning live fish collections, transfers and introductions;

(ii) a review of factors to be considered in selecting suitable donor stocks;

(iii) an evaluation of brood requirements in the context of different enhancement techniques;

(iv) and a discussion of brood stock acquisition in relation to salmon management policy.

Criteria are presented as they are developed throughout the text and a complete list is included in the summary.

LEGISLATION

Transportation of live fish, including eggs, into or within the Province of Newfoundland and Labrador is regulated by the Department of Fisheries and Oceans. Such regulation is aimed at protecting the stock size of fish, maintaining genetic characteristics of fish or fish stocks and preventing the introduction or spread of fish diseases.

Written permission for obtaining fish can be granted by the Minister of Fisheries and Oceans by virtue of Section 4 of the Fisheries Act, which states:

> 4. "Nothing in this Act precludes the granting by the Minister of written permission to obtain fish and spawn for purposes of stocking or artificial breeding or for scientific purposes."

The Newfoundland Fishery Regulations (NFR), developed under the Fisheries Act, elaborate further on fish introductions and transfers. Authorization is granted only if such actions will not a) introduce diseases considered harmful to fish in the Province and b) adversely affect stock size and genetic characteristics of fish or fish stocks in the Province. Section 5 of the NFR states the following:

> 5. (1) Subject to subsection (2), no person shall introduce live fish into any waters of the Province or transfer such fish from any waters of the Province to any other waters thereof.
>
> (2) The Minister may authorize the introduction into the waters of the Province, or the transfer from any waters of the Province to any other waters thereof, of any fish that
>
> (a) do not have any disease that may be harmful to the protection and conservation of fish in the Province; and
>
> (b) will not have an adverse affect on
>
> (i) the stock size of fish in the Province; or

(ii) the genetic characteristics of fish or fish stocks in the Province.

To prevent the intra-provincial spread of harmful disease, donor fish stocks must be examined by a fish disease specialist. If diseases listed in the Fish Health Protection Regulations are detected, transport of the fish stock may not be permitted. Major factors affecting this decision include the presence/absence of the disease or disease agent in the recipient stream or fish stock and the type of disease detected. It should be noted that the responsibility for fish collections and costs associated with diagnostic services is usually borne by the proponent of an enhancement undertaking.

Imports of cultured fish or eggs of wild fish from other provinces or countries are also subject to the provisions of the Fish Health Protection Regulations. Under these regulations a permit is required prior to importation. Such a permit is granted only after the import products have been certified free of diseases or disease agents listed in Schedule II of that regulation. Also, the local fish health officer must be satisfied that any disease or disease agent, listed in Schedule IV of that regulation and that is present, will not be harmful to the protection or conservation of fish in the province of importation. The following criterion summarizes the DFO legislative and regulatory authority governing fish transfers and introductions:

Criterion 1:

All Atlantic salmon brood stock acquisitions for enhancement purposes are to be in compliance with applicable sections of the Fisheries Act, Newfoundland Fisheries Regulations, and the Fish Health Protection Regulations. Proponents of enhancement undertakings must obtain written permission from the Department of Fisheries and Oceans before commencing brood acquisition operations.

DONOR STOCKS

1) Biological Concerns

Two important questions arise when selecting donor stocks for enhancement purposes:

(i) What race or type of salmon should be selected?

(ii) How many salmon can be removed before salmon production in the donor stream is negatively impacted?

The following looks at these concerns in light of related published literature and presents criteria that should ensure suitable stock selection without impairing production of salmon in donor streams.

Wide variation exists among Atlantic salmon in respect to physical, behavioral and physiological characteristics (Saunders and Bailey 1980). Such differences are explained by the existence of different stocks of salmon and

considerable work has been conducted on the mechanisms governing stock-specific differences and their implications on stocking programs. (Note: a wild stock of salmon was defined by Ricker (1972) as those individuals of a species that spawn in a particular stream and which do not interbreed with other such groups spawning in a different place or in the same place at a different time.)

Diversity in salmon stocks has been explained in terms of both environmental factors and the existence of distinct gene pools. White and Huntsman (1938) posed the question 'Is local behavior in salmon heritable?' They documented an experiment in which salmon fry of known multi-sea-winter (large salmon) origin were placed in a stream that was uninhabited by salmon but was situated in a region which produced primarily one-sea-winter or grilse stocks. Smolt age, sea age at maturity and timing of river escapement of the salmon resulting from the transplanted fry were similar to local stocks. A similar demonstration of environmental influence on salmon behavior was reported by O'Connell et al. (1983). Progeny of salmon collected from the Humber River in western Newfoundland were used as brood stock for the Exploits River in central Newfoundland (Fig. 1). Returning adults had adopted sex ratios and sea ages at maturity similar to the existing Exploits stock. Other authors who have documented the effect of environmental factors such as mean water temperature, river discharge and photoperiod on smolt age and sea age at maturity include Schaffer and Elson (1975), Gardner (1976), Wedemeyer et al. (1980), Power (1981), Saunders et al. (1983) and Martin and Mitchell (1985).

Other researchers have reported on genetic or hereditary control of salmon stock characteristics. Møller (1970) identified genetically distinct populations of salmon on the basis of blood transferrin frequencies. Genetic control of sea age at maturation was reported by both Elson (1973) and Piggins (1974). Saunders and Bailey (1980) reviewed the status of genetic research on Atlantic salmon and its contribution to management of the species.

The implications of these control mechanisms on salmon enhancement programs can be crucial. Saunders (1981) reviewed the roles of environment and genetics in salmon stock diversity and cautioned that swamping of wild stocks with semi-domesticated (hatchery) salmon would harm self-sustaining stocks. Saunders and Bailey (1980) gave an example of a generally unsuccessful enhancement (restoration) endeavor in which smolts of Miramichi River parentage were released in three New England rivers. Later efforts, using progeny of residual local stocks, were successful. Ritter (1975) reported that ocean survival of Atlantic salmon smolts decreased as the distance between the native (donor) river and recipient river increased. A transplant of pink salmon (Oncorhynchus gorbuscha) from British Columbia to Newfoundland may have failed because the marine migration pattern and homing behavior of the donor stocks was unsuitable (Lear 1975). Walker and Lister (1971) evaluated a pink salmon transfer from a mainland British Columbia river to a river on Vancouver Island. They suggested lack of success may have been related to opposite directions of orientation of the donor and recipient streams.

The foregoing has described the mechanisms controlling diversity and has shown that there is enough resilience within the species to allow some adaptation to new environments. However, such adaptation is limited and introductions of salmon may be unsuccessful if mechanisms such as homing are

affected. Saunders and Bailey (1980) pointed out that it is most desirable to use a salmon stock or stocks from the river in which the salmon are being enhanced. However, this is not always possible as salmon may be either non-existent or at such low levels that removal is impractical and will not fulfill the brood requirement. Under such circumstances brood stock must be collected from other watersheds. Porter et al (1986) recommended that, where stocks are to be restored, spawning populations that have a stock structure (biological characteristics) similar to the original population should be used as a donor or brood source. They predicted that this would ensure greatest probability of restoration success within the shortest time frame and would safeguard against introgression. Møller (1970) recommended that, to get a stock as genetically suited as possible, salmon stocking programs in previously uninhabited areas should utilize brood sources produced from similar type habitat. Also, to ensure a wide genetic range, Møller indicated that large numbers of juveniles should be used to stock newly-opened areas and, if possible, more than one donor source should be used.

Anon. (1978a) reviewed enhancement activities utilizing adult salmon transfers in Newfoundland and, as a result of the successes at Great Rattling Brook and Torrent River, recommended the following criteria for brood stock acquisition.

- donor stocks should have similar biological characteristics to stocks in recipient systems;
- the mouth of the donor stream should be in the same general area as the mouth of the recipient stream with similar directional orientation of outflows;
- both streams should be in the same geological formation;
- the water chemistry of both streams should be similar.

Fedorenko and Shepherd (1986) developed tentative guidelines for salmon transplants by reviewing past successful transplant activities of sockeye salmon (Oncorhynchus nerka), chinook salmon (O. tshawytscha), coho salmon (O. kisutch), chum salmon (O. keta), pink salmon and Atlantic salmon. Their guidelines for selecting suitable donor stocks emphasized geographical proximity of the receiving system, access to brood sources and compatible biological and environmental characteristics between brood sources and recipient areas. These guidelines, while primarily aimed at Pacific salmon stocks, provide general direction in selecting genetically-suited Atlantic salmon donor stocks adapted to conditions of recipient areas.

A key component of a successful Atlantic salmon enchancment project is selection of suitable brood stock. The following criterion outlines characteristics of the donor stocks and sites that will maximize the likelihood of success.

Criterion 2

If possible brood stock for Atlantic salmon enhancement purposes should be collected from the river in which enhancement activities are planned. If brood stock must be collected from other rivers the following should apply:

(i) the donor stream should be located as close as possible to the recipient stream and should have a similar directional orientation of outflow. Both streams should drain the same or similar geological formations and should have similar water chemistries;

(ii) the donor and recipient streams should be physically similar in respect to size, gradient, flow patterns, distribution of pools, and bottom type;

(iii) in restoration activities donor stocks should have biological characteristics similar to the original stock;

(iv) in activities aimed at developing stocks in newly-opened habitat, the donor source should have biological characteristics similar to those found in salmon in the local area. If possible and practical more than one brood source should be used.

In addition, safeguards are required to protect the integrity of the remaining donor stream stock. Researchers have agreed that certain stock characteristics (size at sexual maturation; timing of river escapement, etc.) are at least partially genetically influenced (Saunders 1981). Selective removals of salmon expressing distinct, genetically-influenced characteristics over a number of years may remove that component from the gene pool of the stock. Procedures are required to ensure brood stock is collected systematically and there is not enough latitude to allow bias towards a particular stock characteristic (i.e. large salmon) unless such is the authorized intent of the undertaking.

Non-systematic removals from a donor stock may also reduce the probability of enhancement success in the recipient stream. A specific example occurred at St. Mary's Bay, Newfoundland where brood were being collected to develop a salmon run in a previously uncolonized river. It was decided that no brood would be removed until egg deposition and projected angling requirements were met in the donor stream. In 1983 a total of 500 salmon were released before 387 (10 large salmon, 377 grilse) were collected for brood purposes. Subsequent sampling of the brood stock showed a M:F sex ratio of 1:17.4 (Meaney 1984). In 1984 and 1985 brood were collected on the basis of 1 out of every 4 grilse and 1 out of every 4 large salmon throughout the run. The M:F sex ratio of the brood stock in 1984 was 1:9.1 (Meaney 1985) and in 1985 was 1:10.7 (Greene 1986). This information suggests that timing of migration of different components of the stock varies and biased brood stock selection may result in over or under selection of important stock characteristics.

Criterion 3

Brood stock for Atlantic salmon enhancement purposes should be removed systematically throughout the run.

Several investigators have researched the possibility of utilizing 'kelts' (post-spawners) as a source of brood stock. Attempts have been aimed at capturing kelts during their seaward migration (either the fall, winter, or spring following spawning), reconditioning them in salt or fresh water, and

utilizing them as brood stock for enhancement or maintenance operations. The potential of using reconditioned kelts for brood stock has, in the past, appeared attractive due to the relative ease of capture at certain sites, and known stock origin of the fish.

Ducharme (1972) noted that in some Nova Scotia rivers, high post-spawning survival of salmon was followed by very low escapements of previously spawned fish. He suggested that if kelts could be reconditioned, a brood source not normally available could be utilized. In his experiment, 23 fish were captured during spring migration, acclimated to salt water, and held in tanks throughout the summer. He found that the reconditioned kelts left in salt water did not mature sexually; those reacclimated to fresh water in the early autumn exhibited normal sexual maturation at spawning time. After spawning, the reconditioned kelts were again acclimated to salt water; in the following three months, 100% mortality occurred. Also, no alevins produced from the reconditioned kelt eggs survived more than 'a few days'. Ducharme (1972) felt further research was required, but suggested reconditioned kelts may one day play an important role in artificial propagation of Atlantic salmon.

Hill (1978) presented results of a study utilizing 24 Atlantic salmon kelts that were captured at East River, Sheet Harbour, Nova Scotia and reconditioned at the Federal Fish Hatchery, Antigonish, Nova Scotia. He concluded that Atlantic salmon kelts can be reconditioned in fresh water with the use of a prepared diet. Although growth of the reconditioned kelts did not compare with the growth of maider large salmon, Hill (1978) reported that all kelts spawned in the first fall, about four months after feeding was initiated. Gray (1980) reported that egg to smolt survivals of reconditioned kelt progeny compared favorably with progeny of hatchery and wild parentage. He indicated that kelt reconditioning was a means of enhancing production of scarce brood stock strains and could be applied operationally in Atlantic salmon enhancement programs in the Maritime Provinces of Canada.

In Newfoundland, experiments on reconditioning kelts have met with only limited success. Mercer and Anderson (1974) reported high mortality in an experiment using Exploits River stock kelts acclimated to the salt water environment with only five fish surviving to spawning out of a total of 83. Reasons reported for the high mortality included handling, predation, and acclimation. At St. Mary's Bay North two attempts have been made to secure brood stock by reconditioning kelts (Meaney 1984, 1985). In the autumn of 1982, 147 kelts were placed in a predator-proof cage at the spawning channel and overwintered successfully. In June, 1983, these kelts were acclimated to salt water and fed a diet of capelin and prepared food during the summer. In October, 1983, the kelts were reintroduced to fresh water and returned to the spawning channel. A total of 52 kelts survived to spawning time and it was observed that 16 female and 11 male fish had matured sexually. Most mortality occurred during acclimation to salt water (33 fish) and reacclimation to fresh water (25 fish). Other mortalities occurred throughout the feeding season and were attributed to starvation and meshing in the netting of the sea cage. Viability of the 35,000 eggs produced by the kelts could not be determined due to massive silting (and subsequent mass mortality) after the eggs were planted in the spawning channel.

A similar experiment at North Harbour in 1984 again resulted in high mortality due to acclimation and non-feeding (Meaney 1985). Of the 305 kelt available after spawning in 1983 only 25 survived to October, 1984. Subsequently it was found that only five of the remaining kelts reached sexual maturity. Recently, research using Atlantic salmon kelts of both Exploits River and Indian Brook origin has been conducted in the Halls Bay and Green Bay areas of Notre Dame Bay. These kelt have been acclimated to salt water and fed throughout the summer in sea cages. Although survivals have been significantly higher than those reported by Meaney (1984, 1985) rates of maturation remain low (V. Pepper, Department of Fisheries and Oceans, P. O. Box 5667, St. John's, Newfoundland A1C 5X1, pers. comm.).

While Atlantic salmon kelt reconditioning appears to hold promise as a means of supplying brood stock for enhancement purposes the technology in Newfoundland is not yet well refined. Further research is required into acclimation (both fresh water to salt water and vice versa), feeding, fecundity and viability of eggs and alevins before it can be considered as a major means of brood stock acquisition. In the meantime it may serve as a technique for restoring scarce stocks which are producing far below optimum levels.

Criterion 4

Until further research provides methods to produce viable salmon fry from reconditioned Atlantic salmon kelts in a cost-effective manner it is recommended that kelt reconditioning not be proposed as a major means of brood stock acquisition for salmon enhancement projects in Newfoundland. One exception that should be considered would be actions aimed at restoring scarce or nearly extinct, discrete salmon stocks.

Infrequently it has been suggested that the commercial fishery should be investigated as a potential brood source. The modus operandi envisaged for such an undertaking has been buying live fish from commercial fishermen at market (or above market) prices. The rationale for utilizing this method would be that as these fish, once caught, are considered removed from the stock, their use as brood stock would have no impact on any fisheries or spawning requirements.

Past assessments of this method have usually cited three areas of concern: disease transmission, genetic and natal origin of the fish, and logistics. As each fish is a potential carrier of undesirable pathogens, quarantine facilities and extensive disease surveys would be required. It has been suggested that each fish would require isolation which would be too costly and impractical for most enhancement projects.

The second concern related to obtaining brood from the commercial fishery is the unknown origin of the fish. As has been stated earlier in this document, researchers such as Møller (1970), Ritter (1975), and Saunders and Bailey (1980) have noted higher success rates when brood stock are acquired from streams in close proximity to the recipient river which have similar fish habitat characteristics and geographic orientation. By utilizing fish of

unknown origin for brood stock, genetic characteristics which are either not desired or not even viable may be expressed in the subsequent offspring.

The degree of complexity in the logistics of obtaining brood stock from commercial fisheries would obviously vary between sites. However, factors such as tending nets to remove fish as soon as caught, transporting the fish to a central collection site, holding facilities, and acclimation to fresh water would likely require an inordinate amount of time, money, and effort. Although marine salmon tagging activities have illustrated that salmon can be caught in gill nets, tagged, and returned alive to the marine environment, it is not known if commercially caught fish could be transported to a holding area in the numbers required without excessive mortality. Also, because of the distribution and isolation of salmon berths, a very high demand would be placed on technical advisors and equipment.

Criterion 5

The acquisition of brood stock for Atlantic salmon enhancement projects in Newfoundland from the traditional commercial fishery is not recommended unless disease surveys and stock discrimination studies indicate a disease-free, genetically-suited stock is available. Such investigations along with the proposed logistical costs, must be considered on the basis of a cost-effective approach to the project.

The second question to be considered concerning brood stock acquisition from wild Atlantic salmon stocks is the number of salmon that can be removed before production in the donor stream is impaired. Fedorenko and Shepherd (1986) examined this question mainly in the context of chinook and sockeye salmon and presented calculations used to determine brood availability. In terms of Atlantic salmon there is considerable debate over what constitutes 'optimum' production and target egg depositions that should be met before brood stock acquisition can be considered.

The relationship between egg deposition and salmon productivity has been discussed by many researchers and varying levels of egg deposition required for maximum production have been proposed. The most widely used estimates were presented by Elson (1975). From research on Atlantic salmon in Pollett River, New Brunswick, he reported optimal spawning occurred when potential egg depositions ranged from 240-300/100 m^2. The virtual egg deposition (potential deposition minus natural and fishing mortality) for optional spawning was reported to be in the order of 170 eggs/100 m^2. Elson suggested that smolt production from egg depositions higher than this figure (170/100 m^2) could actually be reduced due to inter-year-class competition among juveniles. Symons (1979), however, postulated that optimum egg deposition would vary with smolt age. He recommended minimum egg depositions of 220/100 m^2 for 2+ smolts, 165-220/100 m^2 for 3+ smolts and 80/100 m^2 for 4+ smolts.

Several authors have noted other factors that affect the egg deposition requirements of streams. Kennedy (1982) reported that Northern Ireland streams appeared to have much higher juvenile salmon densities than the Miramichi River. He noted that this difference was probably due to a combination of climatic factors, food supply, densities of competing fish species and

suitability of habitat studied and concluded that it is most unwise to extrapolate optimum stocking densities from one river to another. Chadwick (1985) made a similar observation, noting that one of the limitations in setting standard egg deposition rates is the lack of equivalency in rearing habitats between rivers.

Attempts have been made at establishing a standard Atlantic salmon egg deposition rate for rivers in Atlantic Canada. During the Atlantic Salmon Review of 1978 (Anon. 1978b) actual or virtual egg requirements ranging from 150-225/100 m^2 were recommended for various production areas in Newfoundland. These numbers compare favorably with the figure of 170 eggs/100 m^2 reported by Elson (1975). The Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) has attempted to establish an egg deposition standard for use in assessments of various stocks. During a workshop on Atlantic salmon stock assessment and modelling in 1980 optimum spawning escapements and egg depositions were investigated. The Working Group concluded that, in particular areas where historic egg depositions were unavailable due to lack of data, a target egg deposition of 240 eggs/100 m^2 be maintained.

The above estimates are related to egg depositions required to fulfill the rearing potential of juvenile salmon in stream or river habitat. Several researchers have investigated and reported the role of standing water (small lakes and ponds) in rearing of juvenile salmon in Newfoundland. Pepper (1976) and Chadwick (1982) have acknowledged that salmon parr rear extensively in some standing waters in Newfoundland. O'Connell and Reddin (1983) reported egg depositions of up to 1520/100 m^2 and 810/100 m^2 respectively for two Newfoundland rivers. They suspected extensive parr rearing in standing waters may account for these seemingly high egg depositions and suggested that egg deposition requirements based on stream rearing habitat are insufficient for systems containing large areas of accessible standing water.

Research is underway in Newfoundland to determine the rearing potential of standing waters. Shallow, rocky ponds with high dissolved oxygen and low predator/competitor pressure have been found to represent ideal rearing areas for Atlantic salmon parr (Pepper 1976). M. F. O'Connell (Department of Fisheries and Oceans, P.O. Box 5667, St. John's, Newfoundland A1C 5X1 pers. comm.) has evaluated egg depositions in two watersheds in Newfoundland that are characterized by large areas of accessible standing water that meet the criteria of Pepper (1976). He has calculated the egg deposition that could be attributed to pond rearing potential equalled 500 to 700 eggs/ha of accessible standing water surface area. Pepper et al. (1984) reviewed past research on stocking densities of standing water areas and concluded that 1000 fry/ha is a conservative value for Newfoundland. The wide variation between the natural estimates of O'Connell (pers. comm.) and the potential stockings of Pepper et al. (1984) may indicate that standing water areas in Newfoundland are not and may never be used to their potential by natural spawners. In reality this would not be surprising as the main factors affecting density of fry in standing waters are probably adult spawning distribution and the limited movement of fry (Pepper et al. 1984).

Criterion 6

Removal of brood stock from wild Atlantic salmon stocks in Newfoundland should be permitted only if it is ensured the egg deposition requirements of the donor stream are fulfilled. It is preferable if site-specific surveys are conducted to determine egg deposition requirements of donor streams. However, in the absence of such information the following requirements should be met:

(i) 240 eggs/100 m^2 of total stream habitat;
(ii) 700 eggs/ha of accessible standing water surface area.

It is conceivable that a salmon enhancement opportunity may exist close to a potential donor stream that meets the requirements of Criterion 2 but does not have a large enough salmon population to meet Criterion 6. If brood stock cannot be acquired in a cost-effective manner from kelt reconditioning (Criterion 4) or the traditional commercial fishery (Criterion 5) either the opportunity must be ignored or another approach to brood stock acquisition must be taken. One consideration may be compensatory stocking. Under this approach the removal of brood stock would deplete egg deposition in the donor stream to levels below that recommended in Criterion 6 (240 eggs/100 m^2 of total salmon habitat; 700 eggs/ha of accessible standing water area). However, during the following spring salmon fry would be returned to the donor system to compensate for the reduced production due to brood stock removal. The key to such an approach would be the enhanced egg to fry survival rate resulting from the particular fish culture technique used.

The use of the compensatory stocking approach in Newfoundland as a means of justifying brood stock acquisition has been limited and its success, both in terms of supplemental smolt production and cost-effectiveness, has not been determined. However, there is evidence to suggest such an approach could compensate for lost egg deposition. Elson (1975) reported that deficient spawning of a salmon stock had been successfully supplemented by stocking of underyearlings in Pollett River, New Brunswick. The success of the main technique used in compensatory stocking, namely fry stocking, has been demonstrated on the Exploits River (O'Connell et al. 1983). It should be noted that this success was achieved despite the standing stocks of landlocked salmon and brook trout (Salvelinus fontinalis) in the recipient areas.

The effectiveness of compensatory stocking may, however, be impaired in areas where natural spawning by anadromous adult salmon has occurred. To ensure 'proper' compensation it must be determined if brood removal has resulted in a reduction in egg deposition throughout the river or at certain specific sites. Lack of information could result in overstocking of certain areas which may, according to Elson (1975), severely reduce survival to the smolt stage due to competition between year classes. It is also important to ensure compensatory fry are stocked into suitable habitat; Symonds and Heland (1978) observed predation when fry were introduced to areas frequented by salmon parr. Another major question concerning compensatory stocking is the amount of compensation required. It can be reasonably argued that 1) due to stress related to collection and transfer of fry and 2) predation by and competition with existing fish species, compensatory stocking should be conducted at a rate greater than 1:1 in order to fully replace the lost

production. In some rivers in the Maritime Provinces of Canada compensation in the order of 2X or 3X the estimated natural fry production loss is undertaken (R. Cutting, Department of Fisheries and Oceans, P.O. Box 550, Halifax, Nova Scotia B3J 2S7, pers. comm.).

Compensatory stocking may be an important enhancement tool in areas where sources of brood stock are limited. However, this method must be evaluated on 1) an economic basis to ascertain the impact of this technique on the overall cost-effectiveness of the project and 2) a biological basis to ensure such stocking will, in fact, compensate for brood stock removal.

Criterion 7

Compensatory stocking (i.e. compensating for brood removal with salmon fry) should be considered as a means of acquiring brood stock for Atlantic salmon enhancement purposes in Newfoundland when:

i) other brood sources are not available;

ii) it can be justified on a cost-effective basis;

iii) salmon spawning areas and fry habitat in the donor stream have been identified;

iv) a fry stocking plan is developed that will compensate for lost egg deposition to the levels recommended in Criterion 6, (240 eggs/100 m^2 of total stream habitat; 700 eggs/ha of accessible standing water area).

BROOD STOCK REQUIREMENTS

A variety of salmon enhancement techniques have been used over the past 30 years in Newfoundland and each technique has a different level of brood requirement. These techniques, either developed or refined in Newfoundland, range from the simple to the sophisticated and each has proven successful under certain conditions.

It must be reiterated that cost is a major constraint on enhancement activities. Techniques are now available to increase egg to fry survival from the natural rate of approximately 20% (Porter 1975) to over 80% (O'Connell et al. 1983). However, the costs associated with applying such a technique may make it suitable only when relatively large numbers of salmon can be produced. Other less sophisticated (and less costly) techniques are available when the benefits (including number of returning salmon) are not large enough to warrant large-scale investment.

Many of the enhancement activities in Newfoundland are aimed at developing salmon in suitable spawning and rearing habitat that is inaccessible due to natural and artificial barriers. Farwell and Porter (1976) reported that 35% of the suitable habitat in the Province of Newfoundland is inaccessible. Techniques used to colonize these inaccessible areas include opening the area

(through blasting, channelizing or fishway construction) and either allowing colonization through straying from downstream populations or stocking the newly opened areas with salmon adults or fry. Most (probably all) of these inaccessible areas support resident fish populations, including brook trout and/or nonanadromous (landlocked) Atlantic salmon. Fedorenko and Shepherd (1986) recommended that, preferably, recipient waters should have no wild stocks as this would lessen the potential for genetic pollution, reduce predation and competition and reduce the risk of disease transmission. In Newfoundland a similar concern has been expressed, especially in areas inhabited by nonanadromous or landlocked salmon. Payne (1974), on the basis of genetic divergence between anadromous and nonanadromous salmon stocks, recommended reconsideration of opening and stocking habitat that had large, established, nonanadromous populations. This concern was reiterated by Sutterlin and Maclean (1984), again on the basis of introgression between the two groups and swamping of the gene pool of the colonizing anadromous populations by the nonanadromous group. Past experience in Newfoundland has shown this concern has not affected stocking programs. O'Connell et al. (1983) reported that nonanadromous Atlantic salmon are widespread throughout the entire Exploits River watershed. However, an adult salmon stocking program at Great Rattling Brook (a major tributary of the Exploits) was successful. O'Connell et al. (1983) suggested that the gene pool of the nonanadromous stocks may actually have been swamped by the introduction of anadromous Atlantic salmon adults. Creation of an anadromous population of salmon above a natural barrier on the Exploits River by fry stocking was also reported by O'Connell et al. (1983). These fry were stocked into areas known to have established nonanadromous salmon stocks. It would appear that the presence of nonanadromous salmon stocks in the inaccessible habitat of Newfoundland rivers is not a major concern in relation to enhancement potential.

The following reviews the relative merits and disadvantages of various enhancement techniques as outlined by Pratt and Rietveld (1973), Farwell and Porter (1976), Pepper and Oliver (1986) and O'Connell and Bourgeois (1987) and discusses each technique in terms of brood stock requirements.

a) Natural Straying

Colonization by straying from existing Atlantic salmon stocks is the simplest and least expensive method of enhancing salmon production in newly-opened areas. A major factor governing success of this technique is the rate of straying. Atlantic salmon have a strong homing instinct (Banks 1969). Evidence of this behavior was noted by Anderson (1985) who reported that out of the 815 returns from over 41,000 tags applied to salmon smolts and adults at Sandhill River, Labrador, none were from other watersheds. This indicates that attempts to colonize an entire watershed solely by natural straying would probably fail.

The natural straying technique has been used with some success in Newfoundland where a salmon population existed downstream of the newly-opened habitat. At Terra Nova River in Newfoundland a fishway was constructed at a complete barrier to fish migration. Straying, determined from counts at another fishway located downstream, averaged 12 percent of the salmon in the mid-river, similar to the straying rate into new habitat of 10 percent reported

by Anon. (1978a). Although Farwell and Porter (1976) reported that, after 20 years of natural straying, production was increased by 1,000 adult salmon on Terra Nova River, O'Connell and Reddin (1983) reported that egg depositions were substantially short of target spawning requirements.

Both Pratt and Rietveld (1973) and Pepper and Oliver (1986) noted the gradual nature of increases related to natural straying, especially in comparison to results from other methods used in colonization projects. Alexander and Galbraith (1982) reported that although the technique was attractive with regard to cost, the length of time to achieve full production and the possibility of not obtaining suitable numbers and types of stray salmon to seed the area were serious disadvantages. In terms of a capital intensive investment such as a concrete fishway, such uncertainties would be a major concern, especially in light of the relatively low straying rates that have been reported.

Natural straying has been a widely used colonization technique over the past 35 years in Newfoundland in the 'stream remedial' program. Under this program a crew surveyed both partial and complete barriers to salmon migration and, where possible, improved or opened access by means of blasting, installation of baffles, etc. Over 100 stream remedial projects have been completed. Most of the projects have been conducted on relatively small streams (drainage area < 300 km^2) or tributaries of larger rivers and potential production of areas newly-opened has averaged less than 500 adult salmon. Average cost per project has been less than $10,000 (1986 dollars). Although results have not been critically evaluated, observations from field staff have indicated that passage has been eased at existing partial obstructions and numerous small areas of habitat, previously inaccessible, have been successfully colonized.

Criterion 8

Colonization of newly-opened habitat by natural straying of Atlantic salmon is recommended when:

(i) a salmon population exists downstream;

(ii) potential production of the newly-opened habitat is less than 500 adult salmon;

(iii) costs related to opening the area are less than $10,000.

b) Adult salmon transfers

Adult transfers have been used successfully in Newfoundland to establish Atlantic salmon populations in newly-opened areas. Pratt and Rietveld (1973) reported that an adult salmon transfer operation enhanced colonization of Great Rattling Brook, a tributary of the Exploits River. Brood stock were acquired from Rattling Brook, an adjacent river system flowing into the Bay of Exploits. Farwell and Porter (1976) compared the Great Rattling Brook adult transfer with results from the colonization by natural straying of newly-opened habitat on Terra Nova River. They concluded that the rate of enhancement of salmon

production was three times greater at Great Rattling Brook. Anon. (1978a) outlined results of an adult salmon transfer at Torrent River in Newfoundland and concluded that this technique is an effective means of enhancing salmon populations. The brood stock were collected from West River, located approximately 75 km north, and flowing in the same direction (east to west). Adult salmon transfers may also be considered attractive from an economic point of view as there is no requirement for capital investment into egg incubation/fry rearing facilities and no annual fry distribution costs.

Alexander and Galbraith (1982) discussed the disadvantages of adult salmon transfers, especially as they relate to brood stock removal. They pointed out that large scale removals may be required if newly-opened areas are to be stocked to the optimum (i.e. 240 eggs/100 m^2). Such removals can cause adverse public relations and finding rivers capable of providing the numbers required may be difficult. The potential for loss of eggs in the newly-stocked area due to severe flooding, ice scour, etc., was also noted by Alexander and Galbraith (1982).

Regardless of the disadvantages noted above the adult salmon transfer technique has proven successful in Newfoundland. It is especially attractive where there is a relatively large brood stock available and an enhancement opportunity exists that has a high production potential but capital investment funds for egg incubation/fry rearing facilities are not available. Also, it is attractive when operating funds are limited to periods less than 12 months per year.

Criterion 9

Enhancement of newly-opened habitat by adult Atlantic salmon transfers is recommended when:

(i) potential production of the newly-opened habitat is greater than 500 adult salmon;

(ii) a suitable brood stock is available (in terms of both egg deposition requirements for donor and recipient rivers and biological characteristics of the donor stock);

(iii) the projected numbers of salmon returning can economically justify trapping, holding and transferring of adult salmon. Funds for capital costs related to egg incubation facility construction and ongoing costs for maintenance and salmon fry distribution can either not be economically justified or are not available.

c) Salmon fry stocking

Fry stocking has been found to be an effective means of enhancing salmon production in newly-opened habitat in Newfoundland. Pratt and Rietveld (1973) found that on the Exploits River fry stocking resulted in smolt productions that indicated a rapid establishment of a salmon population in habitat previously not utilized by anadromous salmon. Farwell and Porter (1976) reported that fry stocking resulted in salmon populations being established

more rapidly than by adult stocking. They also recommended fry stocking when supplies of brood stock are limited. O'Connell et al. (1983) concluded that, based on fry stocking activities on the mid-Exploits River and subsequent adult returns, fry stocking is an effective and efficient use of brood stock. They compared returns from fry stocking with returns from natural spawning on Great Rattling Brook and reported that egg incubation and fry stocking resulted in an increase in production of adult salmon of 3.4X the natural rate. O'Connell and Bourgeois (1987) compared results on the Exploits River from adult stocking at Great Rattling Brook and fry stocking at Noel Paul's Brook. They concluded fry stocking resulted in establishment of runs in roughly one-half the time required for adult stocking and with less than one-half the brood stock requirement.

Although fry stocking appears to be an attractive enhancement technique, several factors must be considered to ensure the appropriateness and success of the method. The key to the high return per brood fish in Newfoundland is the high egg to fry survival rates of 80% or greater (O'Connell et al. 1983) resulting from using deep substrate incubation boxes. These egg incubators, described by Pepper (1984), vary in cost due to local conditions. However, it has been estimated that filters, plumbing, concrete and shelter for a 1,000,000 egg capacity incubation box would be in the range of $100,000 (R. Goosney, Department of Fisheries and Oceans, P.O. Box 5667, St. John's, Newfoundland, A1C 5X1, pers. comm.). This estimate does not include costs for construction of a diversion or head dam. Other ongoing costs related to fry stocking operation include brood stock capture, holding, transport and security, egg stripping and fertilization and winter security. In addition, Alexander and Galbraith (1982) pointed out a major drawback of fry stocking is the manpower and money needed to conduct the intensive dispersal type stocking that is required. The end result is that a large potential production must be identified before a new egg incubation facility to support fry stocking operations can be economically justified.

An important factor governing the success of a fry stocking operation (and, indeed, the amount of brood stock required) is the proposed fry stocking density. Optimum stocking densities have long been a matter of discussion and debate and have been addressed by numerous authors.

Fry stocking densities recommended by researchers in Great Britain have ranged from 100/100 m^2 (Gee et al. 1978) to 1,000/100 m^2 (Egglishaw et al. 1984). McCarthy (1985) recommended a density of 500 fry/100 m^2 for stocking streams in Ireland. Kennedy (1982) concluded from work in Northern Ireland that the optimum fry stocking density of a river could only be determined after careful assessment of local conditions and resident fish populations. The variation in productivity of different habitats was also noted by Egglishaw et al. (1984) who attempted to classify various stream habitat types and assign a stocking density (from 200 fry/100 m^2 to 1,000 fry/100 m^2) on the basis of production potential.

Fry stocking densities recommended by researchers in Atlantic Canada are generally lower than the figures reported from Britain and Ireland. Elson (1975) reported that, on the basis of studies on the Pollett River in New Brunswick, smolt production was maximized when fry were planted at a density of

48/100 m^2. Symons (1979) suggested that optimal egg depositions varied with smolt age. If a 20% egg to fry survival (Porter 1975) is applied to the optimal values suggested by Symons fry densities would be as follows: for 2+ smolt - 44 fry/100 m^2, for 3+ smolt - 33 to 44 fry/100 m^2, for 4+ smolt - 16 fry/100 m^2. In Newfoundland Sturge (1968) recommended that, on the basis of work at Indian Brook, the optimum level for stocking was 48 fry/100 m^2. Pratt and Rietveld (1973) compared survival to the fingerling (0+) stage resulting from stockings at densities of 42, 54 and 84 fry/100 m^2 on Exploits River and reported highest survival at the 54 fry/100 m^2 density. More recent investigations have indicated that somewhat higher densities may be required to reach optimum production. O'Connell et al. (1983) reported that stocking densities of fry during the Exploits River salmon enhancement project have increased from a mean of 42/100 m^2 for the period 1968-75 to a mean of 75/100 m^2 for the period 1976-80. They concluded that the increased densities had resulted in increased smolt production with no unnecessary mortality of fry. O'Connell and Bourgeois (1987) have reaffirmed this conclusion and speculated that the apparent increased rearing capacity may be due to the presence of lakes and ponds on the Exploits system. Also, they cautioned that, like the conclusion of Kennedy (1982), it may not be appropriate to extrapolate optimum fry stocking densities from one river to another.

O'Connell et al. (1983) also discussed other factors which could affect the success of the Exploits River enhancement project. In relation to fry stocking they reviewed literature concerning fry behavior and preferred habitat and suggested that survival may be increased if fry were released in shallow, slow velocity areas away from pools and riffles. This would allow time for fry to acclimate to new surroundings away from most predators. In addition, O'Connell et al. (1983) discussed the rate of dispersal and concluded that although even dispersal throughout the watershed was desirable, in practice it was not always possible due to the numbers of fry to be stocked, the size of the watershed, accessibility, etc.

Criterion 10

Enhancement of newly-opened habitat by Atlantic salmon fry stocking is recommended when:

(i) potential production of the newly-opened habitat can economically justify construction of egg incubation facilities and annual costs related to brood stock collection, holding, stripping, egg incubation and fry distribution and such funding is available. (Note: use of an existing egg incubation facility would substantially reduce capital costs.);

(ii) a suitable brood stock is available in terms of biological characteristics but is not available in terms of numbers required to seed the newly-opened area naturally;

(iii) it is socially important to decrease the time of development and bring the newly-opened habitat to full production levels.

Criterion 11

In typical Newfoundland rivers that contain areas of standing water throughout the watershed a stocking density of 75 fry/100 m^2 is recommended. In atypical rivers containing little or no standing water a stocking density of 50 fry/100 m^2 is recommended.

Criterion 12

Salmon fry should be distributed into habitat suitable for underyearling salmon. Such habitat is typically found in shallow, low velocity areas along stream perimeters away from pools and riffles.

DISCUSSION

The foregoing has presented criteria for brood stock acquisition for Atlantic salmon enhancement projects on the basis of scientific and economic justifications. There is, however, one further factor to be considered in respect to brood acquisition - the priority of brood removal in terms of the overall management of the species.

The principal objectives of the management program for Atlantic salmon,as stated in 'Management of the Atlantic Salmon in the 1980's - A Discussion Paper' (Anon. 1982), are:

1. to optimize net benefits to Canadians from both the existing resource and enhancement opportunities on a continuing basis;

2. to ensure distribution of the benefits among authorized users of the salmon resource in accordance with social and economic values; and

3. to administer the program in consultation with provincial governments, user groups and other interested parties.

The first priority in allocating the resource is to satisfy resource conservation requirements. After conservation requirements are met the remainder of the resource will then be shared equitably among authorized resource users (Anon. 1982). In addition, efforts are underway to manage salmon on a zonal basis that takes into account the biological, economic and social differences throughout the range of the species. In Newfoundland, 14 production zones have been identified (Fig. 1) and Zone Management Advisory Committees have been established to provide advice and recommendations on salmon management within their respective zones.

Enhancement is a potentially important component in the management of Atlantic salmon (Anon. 1982). In fact, in order to fulfill objective 1 (to optimize net benefits) enhancement must be considered as a major tool in ensuring salmon stocks are producing at target levels and all available habitat is developed in a cost-effective manner. The priority of brood stock acquisition in Newfoundland should also be considered with respect to the long term benefits that can be produced by using demonstrated technology for salmon

enhancement. The criteria developed have recommended that the spawning requirements of donor streams should be met before any brood stock are removed. If production levels are such that such requirements cannot be met the managers of the resource should thoroughly assess, on both a zonal and regional level, the overall importance and potential benefits that could be derived. Curtailment of traditional fisheries should be considered as an option for brood acquisition when the potential long-term benefits can justify such approach.

SUMMARY

The following criteria are recommended for brood stock acquisition for Atlantic salmon enhancement projects in Newfoundland.

1. All Atlantic salmon brood stock acquisitions for enhancement purposes are to be in compliance with applicable sections of the Fisheries Act, Newfoundland Fisheries Regulations, and the Fish Health Protection Regulations. Proponents of enhancement undertakings must obtain written permission from the Department of Fisheries and Oceans before commencing brood acquisition operations.

2. If possible brood stock for Atlantic salmon enhancement purposes should be collected from the river in which enhancement activities are planned. If brood stock must be collected from other rivers the following should apply:

   (i) the donor stream should be located as close as possible to the recipient stream and should have a similar directional orientation of outflow. Both streams should drain the same or similar geological formations and should have similar water chemistries;

   (ii) the donor and recipient streams should be physically similar in respect to size, gradient, flow patterns, distribution of pools, and bottom type;

   (iii) in restoration activities donor stocks should have biological characteristics similar to the original stock;

   (iv) in activities aimed at developing stocks in newly-opened habitat, the donor source should have biological characteristics similar to those found in salmon in the local area. If possible and practical more than one brood source should be used.

3. Brood stock for Atlantic salmon enhancement purposes should be removed systematically throughout the run.

4. Until further research provides methods to cost-effectively produce viable salmon fry from reconditioned Atlantic salmon kelts it is recommended that kelt reconditioning not be proposed as a major means of brood stock acquisition for salmon enhancement projects in Newfoundland. One exception that should be considered would be actions aimed at restoring scarce or nearly extinct, discrete salmon stocks.

5. The acquisition of brood stock for Atlantic salmon enhancement projects in Newfoundland from the traditional commercial fishery is not recommended unless disease surveys and stock discrimination studies indicate a disease-free, genetically-suited stock is available. Such investigations along with the proposed logistical costs, must be considered on the basis of a cost-effective approach to the project.

6. Removal of brood stock from wild Atlantic salmon stocks in Newfoundland should be permitted only if it is ensured the egg deposition requirements of the donor stream are fulfilled. It is preferable if site-specific surveys are conducted to determine egg deposition requirements of donor streams. However, in the absence of such information the following requirements should be met:

(i) 240 eggs/100 m^2 of total stream habitat;
(ii) 700 eggs/ha of accessible standing water surface area.

7. Compensatory stocking (i.e. compensating for brood removal with salmon fry) should be considered as a means of acquiring brood stock for Atlantic salmon enhancement purposes in Newfoundland when:

i) other brood sources are not available;

ii) it can be justified on a cost-effective basis;

iii) salmon spawning areas and fry habitat in the donor stream have been identified;

iv) a fry stocking plan is developed that will compensate for lost egg deposition to the levels recommended in Criterion 6, (240 eggs/100 m^2 of total stream habitat; 700 eggs/ha of accessible standing water area).

8. Colonization of newly-opened habitat by natural straying of Atlantic salmon is recommended when:

(i) a salmon population exists downstream;

(ii) potential production of the newly-opened habitat is less than 500 adult salmon;

(iii) costs related to opening the area are less than $10,000.

9. Enhancement of newly-opened habitat by adult Atlantic salmon transfers is recommended when:

(i) potential production of the newly-opened habitat is greater than 500 adult salmon;

(ii) a suitable brood stock is available (in terms of both egg deposition requirements for donor and recipient rivers and biological characteristics of the donor stock);

(iii) the projected numbers of salmon returning can economically justify trapping, holding and transferring of adult salmon. Funds for capital costs related to egg incubation facility construction and ongoing costs for maintenance and salmon fry distribution can either not be economically justified or are not available.

10. Enhancement of newly-opened habitat by Atlantic salmon fry stocking is recommended when:

(i) potential production of the newly-opened habitat can economically justify construction of egg incubation facilities and annual costs related to brood stock collection, holding, stripping, egg incubation and fry distribution and such funding is available. (Note: use of an existing egg incubation facility would substantially reduce capital costs.);

(ii) a suitable brood stock is available in terms of biological characteristics but is not available in terms of numbers required to seed the newly-opened area naturally;

(iii) it is socially important to decrease the time of development and bring the newly-opened habitat to full production levels.

11. In typical Newfoundland rivers that contain areas of standing water throughout the watershed a stocking density of 75 fry/100 m^2 is recommended. In atypical rivers containing little or no standing water a stocking density of 50 fry/100 m^2 is recommended.

12. Salmon fry should be distributed into habitat suitable for underyearling salmon. Such habitat is typically found in shallow, low velocity areas along stream perimeters away from pools and riffles.

ACKNOWLEDGMENTS

The author wishes to acknowledge the advice and support of J. D. Pratt who took a keen interest in this publication. The constructive criticisms and reviews of T. R. Porter, M. F. O'Connell, and V. A. Pepper are gratefully acknowledged. The author also wishes to thank Margaret Bursey and Karen Harding for typing the many drafts of this manuscript.

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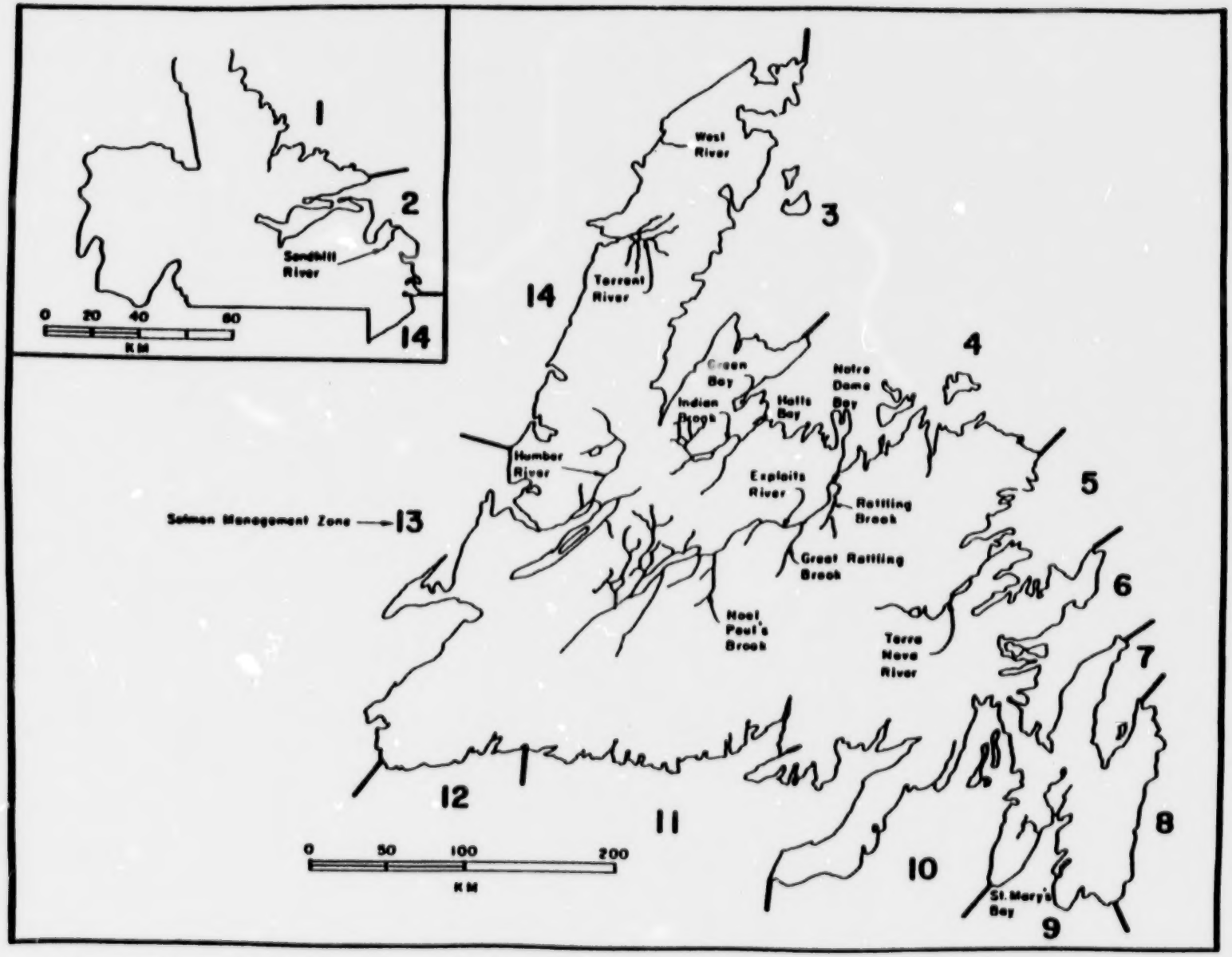

Fig. 1. Sites of Atlantic salmon enhancement activities referred to in the text.